CLASSIFICATION CONFIDENTIAL CONFIDENTIAL

CENTRAL INTELLIGENCE AGENCY
INFORMATION FROM
FOREIGN DOCUMENTS OR RADIO BROADCASTS

REPORT

CD NO.

50X1-HUM

COUNTRY	USSR	DATE OF INFORMATION	1948
SUBJECT	Scientific - Cosmic rays		
HOW PUBLISHED	Book	DATE DIST.	1 NOV 1949
WHERE PUBLISHED	Moscow	NO. OF PAGES	8
DATE PUBLISHED	1948		
LANGUAGE	Russian	SUPPLEMENT TO REPORT NO.	

THIS IS UNEVALUATED INFORMATION

SOURCE Lavinnyye Protessy v Kosmicheskikh Luchakh, State Publishers of Technical and Theoretical Literature, OGIZ. (Information requested.)

AVALANCHE PROCESSES IN COSMIC RAYS

S. Z. Belen'kiy
Phys Inst imeni P. N. Lebedev
Acad Sci USSR

TABLE OF CONTENTS

CLASSIFICATION CONFIDENTIAL CONFIDENTIAL

STATE	X	NAVY	X	NSRB		DISTRIBUTION						
ARMY	X	AIR	X	FBI								

Foreword

The avalanche theory, that is, the passage through matter by high-energy electrons and photons, originated in 1937. Even during its early stage of development this theory solved many knotty problems in cosmic rays, especially the problem of the formation of cosmic ray showers. Although the avalanche theory was applied to a limited field of phenomena in cosmic rays, the theory seems essentially to be a unique unified theory of cosmic radiation. It explains the vigorous development of the cosmic ray theory in the past 10 years. The work of Soviet physicists has been important to the development of the avalanche theory. Results of this work include the method of solving the basic equations of the theory, the establishment of the "soft" character of the avalanche particles' spectrum, the basic results with respect to the scattering of avalanche particles, the theory of Auger showers, and the solution of many other problems.

In 1941 a summary of the avalanche theory appeared in an article by Rossi and Greisen entitled "Cosmic Rays," now available in Russian translation. In spite of the merits of this summary, it is incomplete and in part obsolete. The present work is mainly devoted to the problems worked out in recent years. The basis for this book is the work of Soviet physicists and theoreticians, among whom we must first mention the work of L. D. Landau and I. Ye. Tamm. A considerable part of this book has been written on the basis of the work of the author himself.

This book discusses the theory of the electromagnetic interactions of high-energy electrons and photons with matter. Experimental data is drawn only to illustrate the most important conclusions, namely, the "soft" nature of the spectrum and meson spin.

The author expresses his gratitude to I. Ye. Tamm and L. D. Landau for their valuable advice and instruction, and also to S. N. Vernov and V. I. Veksler for their discussion of many problems.

Introduction

We shall not touch upon here the nuclear processes in cosmic rays, although these processes are of great interest for present-day physics. The theoretical explanation of nuclear processes, to which the origin of the meson is related, the interaction of protons and neutrons with matter in the region of very high energies, "stars," -- at present all these meet with great difficulties in regard to principles (Symposium on the Meson, edited by I. Ye. Tamm, GTTI, 1947).

50X1-HUM

On the other hand, the study of the electomagnetic interaction of cosmic radiation with matter is based upon the successive applications of quantum-relativistic electrodynamics which has been successfully applied up to now to various areas in physics. The extrapolation of the ordinary quantum-mechanical laws to the field of extremely high energies is the specific method used for the problems of this book. The doubts that existed several years ago concerning the possibility of such an extrapolation turned out to be unfounded.

The application of quantum electrodynamics to cosmic radiation has led to very fruitful results and permitted one to tear down both the quantitative and the qualitative walls around the phenomena studied. Moreover, by relying on the quantum-mechanical theory, which has been worked out thoroughly enough during the study of cosmic rays, one can hope to separate the field of cosmic phenomena which is connected with specific nuclear interactions from the field of phenomena which is due to electromagnetic interections. Such a separation seems possible and very important for the construction of a theory of nuclear effects.

In the investigation of the electromagnetic action of cosmic radiation the interaction of electrons and photons with matter is most essential and interesting (henceforth in this book, by the term "electron" we shall mean both electrons and positrons).

Passing through matter, electrons and photons of high energies take part in the following processes: (1) radiational retardation (electrons); (2) processes of pair-formation (photons); (3) ionization losses (electrons); (4) Compton effect (photons); and (5) Rutherford scattering (electrons).

These processes, with the exception of the latter two, are discussed in Chapter I of the present book. In the field of high energies, an important role is played by the first two processes. Bhabha and Heitler (Proc. Roy. Soc. 159, 432, 1937), and also Carlson and Oppenheimer (Phys. Rev. 51, 220, 1937), in 1937 showed for the first time that these processes should lead to the formation of electron and photon "showers." Having been stopped (retarded) inthe nuclear field, the electron creates a photon of energy equal in order of magnitude to the energy of the first electron. The high-energy photon can form with definite probability an electron-positron pair. Each component of the pair, being subjected to radiational retardation, radiates a photon and so on. After many repetitions of such processes we obtain, instead of the initial electron, a great number of photons and charged particles of both signs. During all this, however, the energy of the original is being broken up; therefore, the number of particles with energy greater than a given one at first increases up to a certain maximum and after that the energy quickly falls to zero. The behavior of the electrons and photons during all this is naturally to be described by some integral equations, such as the so-called equations of the cascade theory.

In Bhabha's and Heitler's works, and also Carlson's and Oppenheimer's, the basic equations of the theory were solved only approximately. In the work of the Soviet theoretician Landau (S. Landau and G. Rumer, Proc. Roy. Soc. 16[illegible], 21[illegible], 1938), there was developed a very convenient and complex mathematical method of solving the equations of the cascade theory, by relying upon the Laplace-Mellin transformation. These works were an important step in the study of cosmic rays. They permitted one to clarify qualitatively the "shower" of particles appearing in a Wilson cloud chamber, and they also aided in revealing a new particle, namely the meson. Along with the development of the shower and with the decreasing energy going into the shower's particles there begins to emerge another important role, that played by ionization losses of electrons and by the Compton effect. In addition, the asymptotic terms for the processes of radiational retardation andpair-formation, which terms were employed in the above-mentioned works and which hold true for high energies, are very inaccurate in the area of low energies, especially for light elements. Without an accurate account of the indicated factors in the cascade theory one cannot answer the many questions, interesting from the experimental point of view, and only purely qualitative results can be given. By taking the above-mentioned processes into consideration, we shall obtain for the distribution function of the electrons and photons very complicated integro-differential equations; their solution by means of the Laplace-Mellin method encounters great difficulties.

In the course of the past 10 years, attempts have been undertaken to make the cascade theory more accurate and precise. The first essential progress was made by Snyder's works (Phys. Rev. 53, 960, 1938) and Serber's (Phys. Rev. 54, 317, 1938), in which they solved the equations of the cascade theory, taking into consideration ionization losses. As a result they obtained the so-called cascade curve, that is, the full number of particles as a function of the depth of the layer penetrated by the shower. Firstly, however, in the expression obtained by Snyder and Serber there was introduced a complicated function, taken from an equation in finite differences, only holding true for integral values of the variable (argument); secondly, and more essential, these authors obtained the distribution of electrons and photons with respect to the energies in the shower, thus solving only part of the problem.

In many works on the theory of showers, and in comparatively recent ones (W. Heisenberg, Kosmische Strahlung, 1943), the authors employ an energy distribution spectrum of electrons, calculated by Arley (Proc. Roy. Soc., 168, 519, 1938, and Arley, Eriksen, Danske Videnskabernes Selskab. 17, No 11, 1940) taking into consideration the ionization losses approximately. Meantime, Arley's spectrum appears to be roughly inaccurate (as shown in section 14 of this book), and further study leads to a lower evaluation of the number of electrons with low energies.

In the works of Bhabha and Chakrabarty (Proc. Roy. Soc. 181, 267, 1943, and Proc. Ind. Acad. Sci. 15, 464, 1942) there is developed their cascade theory which takes into account ionization losses and arrives at an expression for the full number of particles; this expression differs from the one obtained by Snyder and Serber. In section 14 of this book it is shown that Bhabha's and Chakrabarty's method also leads to an underestimate of the number of low-energy particles, although in lesser degree than Arley's calculations. The difference of Bhabha's and Chakrabarty's results from those of Snyder's and Serber's is explained by this underestimate, and also the errors of their conclusions pertaining to the energy spectrum of the electrons.

In the work of Corben (Phys. Rev. 60, 435, 1944), an attempt is made to construct a cascade theory, with more accurate expressions for the cross section of pair-formation in heavy particles taken into consideration. A criticism of this work is given in section 18 of Chapter V of this book.

Thus, in the cited works, the processes existing in the field of low energies are considered either for separate problems or roughly approximate.

Chapter II discusses the cascade theory for the field of high energies.

In Chapter III a problem is proposed to find the full solution of the basic equations of the cascade theory, including radiational retardation, pair-formation (whose cross-section is given in an asymptotic form, holding true in the case of complete screening), and ionization losses.

By applying the Laplace-Mellin transformation with respect to the variable E, the energy of a particle, and the Laplace transformation with respect to t, the thickness of the layer penetrated, one can reduce these equations to an equation in finite difference, which was successfully solved. The latter transformation was first applied by the author in 1940. (DAN 33, 609, 1941). In addition, a certain function entering this solution is replaced by an expression closely approximating it in the variables' transformation region. In the case where ionization losses are disregarded, the approximating function leads to a similar one which is also accurate. By means of a transformation to the plane of complex variables, the solution succeeds in presenting the form of a potential series in terms of the small parameter β/E_0, where β is the so-called "critical" energy (see Chapter II) and E_0 is the energy of the original particle.

50X1-HUM

Limiting ourselves to the first term of this power-series expansion, we shall obtain a function which gives the dependence of the full number of particles upon the depth t of the layer, and also the energy distribution spectrum for any depth t. If desired, it is possible to extract even succeeding terms of the expansion; these give, however, for the majority of interesting cases, only small corrections, that is, the first term is sufficient without the second, etc.

The full number of particles calculated in this manner are obtained in the form of an integral in the complex-number plane. This integral is analogous to the corresponding integral calculated by Snyder and Serber. However, in place of one of the integrands, which is determined by Snyder and Serber only for integral values of the variable (argument), we have in our case established an analytic function (complex) which assumes for integral values of the variable (argument) the same values which are in Snyder's and Serber's function. Obviously this integral is calculated by Sommerfeld's method of "passing", given by the first two nondisappearing terms in the expansion of the logarithm of the integrand function in the form of Taylor's series, which corresponds to the first term of the expansion of the solution in a potential series of the quantity $(\log E_0/\beta)^{-1}$. Although β/E_0 is a small quantity, the logarithm of E_0/β can not be very large. For showers formed by the electrons of the atmosphere in lead, it is of the order of magnitude 5. Therefore, during the calculation of the integral, we employed, in the expansion of the logarithm of the integrand function, terms of higher order and the expression obtained by us is thus accurate fully up to quantities of the order $(\log E_0/\beta)^{-2}$.

In 1939, I. Ye. Tamm and the author obtained an "equilibrium" electron-energy distribution-spectrum which was "neutralized" (averaged, etc.) with respect to the total cascade curve. It was obtained as a result of solving the basic equations of the theory, taking into consideration ionization losses. (J. Phys. USSR 1, 177, 1939). In this research the spectrum of delta-electrons and decay electrons was calculated. The basic results of this research are given in Chapter IV, where the energy spectrum of particles for various depths are also calculated. Furthermore, in this chapter the average energies of the particles, as well as the logarithm of the average energy which is essential for a more accurate estimate of ionization losses are calculated. The obtained expressions are compared with the results of other authors, particularly with Rossi's and Klapman's (Phys. Rev. 61, 414, 1942), which are calculated by means of numerical integration. In this chapter, furthermore, the approximate value of the influence of the Compton effect on the electrical distribution of electrons and photons are derived.

Chapter V is devoted to the theory of showers in heavy elements. In the theories developed up to this time, the absorption coefficient for photons is assumed to be equal to a constant, not depending upon the energy's magnitude. Moreover, for heavy elements, particularly for lead, where the process of shower formation proceeds with special intensity, this assumption cannot be considered justified. Actually, the absorption coefficient of photons in lead is not constant, but varies in the essential region of energy variations three times.

In Chapter V the number of particles at the maximum of the cascade curve, and the position of this maximum, taking into consideration the dependence of the absorption coefficient of photons upon energy are also calculated. The essentials of the method are included, in the determination of the connection between the position of the maximum and the number of particles at the maximum, by the expression of the following form:

$$P_n = \int_0^\infty \bar{P}(t, E) \cdot t^n \, dt$$

Sanitized Copy Approved for Release 2011/09/13 : CIA-RDP80-00809A000600260313-5

50X1-HUM

where $n = 0, 1, 2$ and $P(t, E)$ is the function of the distribution of particles with respect to depth (t) and energy (E).

It is shown that the quantity $P_0(E)$ for electrons (the equilibrium energy-distribution spectrum of electrons) for all practical purposes does not depend upon the absorption coefficient of photons and the remaining "moments" of P_n are comparatively simply calculated by means of $P_0(E)$ and by the function that determines the energy dependence of the absorption coefficient of photons.

Chapter VI discusses the transitional effects in cosmic rays. The transitional effect from lead to aluminum and iron is calculated; here it is assumed that the layers of aluminum and iron are sufficiently fine. Because of the low energy of the main part of the cascade electrons, even the fine layers of aluminum and iron absorb a considerable part of them. This circumstance must be considered during any analysis of the influence of the walls of the measuring apparatus (counters, ionization chambers, etc.) upon the results of the experiments.

Particles entering the composition of a shower do not maintain the directions of the original particle but are, on the contrary, deflected because of Rutherford scattering. This leads to a definite distribution of the shower particles with respect to angle and space.

This initial kinetic equations of the shower electrons and photons with respect to angle and space were set up by Landau (ZhETF, 10, 1007, 1940). In this work he also gives a method of calculating the mean square angle of deflection of the shower particles and also the "width" of the shower (mean square spatial deflection).

However, in the calculation of these magnitudes, the angle of deflection was assumed to be small and ionization losses were not taken into consideration. Moreover, by virtue of the fact that the majority of the particles in the shower possesses comparatively small energy, the ionization losses for them assumes considerable importance.

In Chapter VII are calculated the average angles of deflection of the shower particles, taking into consideration ionization losses in the assumption that the angles of deflection are small. This assumption is fulfilled well for light matter (air, aluminum, etc.), where the ionization losses are included before the angle of deflection becomes large.

Furthermore, there is found a function giving the distribution of particles with respect to energy, depth of penetration, and the angle for the case where ionization losses are disregarded and in the assumption that the angles of deflection are small. It is shown that the function of angular distribution is non-Gaussian. This circumstance is related to the fluctuating character of the energy losses in the cascade processes.

In section 25 of Chapter VII a function giving the angular distribution of particles for large angles of deflection and for the case where ionization losses are disregarded is found. Such a consideration possesses significance for the case of heavy elements, lead, for example, where the scattering becomes large for energies that permit one to disregard ionization losses. The data obtained from these considerations is used to evaluate the influence of scattering upon the form of the cascade curve in heavy elements.

At the end of Chapter VII, under the assumption that the angles of deflection are small, the functions giving the angular distribution in space during passage of an electron stream through a layer of matter are calculated. This is done without taking into consideration radiational retardation, but taking into consideration ionization losses. There, by considering that ionization losses are absent, we obtain, as an individual particular case, the distribution functions for multiple (multiplication) scattering of fast electrons, found by Fermi and introduced in Rossi and Greisen's summary (Rev. of Mod. Phys. 13, 240, 1941).

The average "width" of cascade showers, taking into consideration ionization losses, that is, the quantity that plays a large role in the theory of Auger showers, is also calculated in this chapter.

Sections 24 and 28 discuss the nonmultiple (nonmultiplication) scattering of charged particles and its influence upon the angular and spatial distribution of particles.

The results in Chapter VII are obtained by calculating the "moments" of the function giving the distribution with respect to the variable t (the depth of the penetrated layer of matter) and the variables theta and cos theta, where theta is the angle of deflection of the shower particles. The other results are obtained by expanding the distribution function with respect to Bessel functions in the variable cos theta or with respect to Legendre's functions in the variable costheta.

Chapter VIII discusses secondary showers generated by mesons. Here are calculated not only the frequency of the comparatively narrow showers caused by the mutual collisions of mesons with the electrons of the medium (ionization showers) but also the frequency of large showers due to radiational retardation of mesons.

In the account on ionization showers consideration is given to the influence of the meson spectrum. This leads to an expression for the frequency of the showers that differs greatly from the frequencies obtained in the literature.

Furthermore, an analysis of the experimental data on high pulses and a comparison of this data with theoretical results is carried out. A quantitative comparison of the theoretical values of the frequency of large showers (in the assumption that the meson spin is zero) with the experimental data of Schein and Gill (Rev. of Mod. Phys. 11, 267, 1939) is also derived.

From this comparative study it followed that the experimental data was in full agreement with the assumption that large pulses at sea level are generated by means of radiational retardation of zero-spin mesons. The same conclusion was reached earlier by Christy and Kusaka (Phys. Rev. 59, 414, 1941) on the basis of more complicated and less fine considerations. The calculations of Chakrabarty (Indian Journ. of Phys. XVI 377, 1942), who arrived at a directly opposite conclusion, appear to be erroneous, as shown section 32,

Chapter VIII also discusses the influence of radiational retardation upon the absorption of mesons under great thicknesses of matter.

- E N D -